



***James Webb Space Telescope (JWST)
Integrated Science Instrument Module (ISIM)
Cryogenic Component Test Facility***

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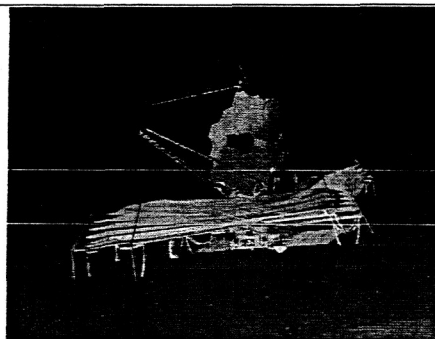
Presentation Overview



- JWST/ISIM Overview
- ISIM Thermal Verification Requirements
 - Emittance Test Objectives
- Cryochamber Design Requirements
- Cryochamber Construction
- Emittance Test Sample Selection and Configuration
- Error Sources and Error Mitigation
- Cryochamber Operation
- Cryochamber and Emittance Sample Test Results



JWST Conceptual Illustration



JWST Overview



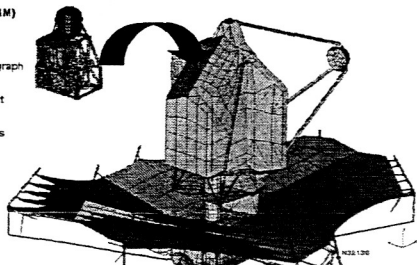
- Large infrared observatory positioned at L2
- Proposed launch date: August 2011
- **Mission goals:**
 - Understand the birth and formation of stars
 - Determine how planetary systems form
 - Explain galaxy formation
 - Determine the shape of the universe
 - Provide a better understanding of the intriguing dark matter problem



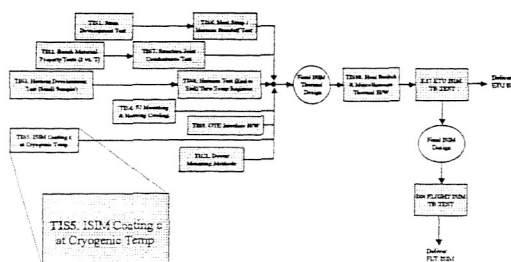
ISIM & Enclosure on JWST

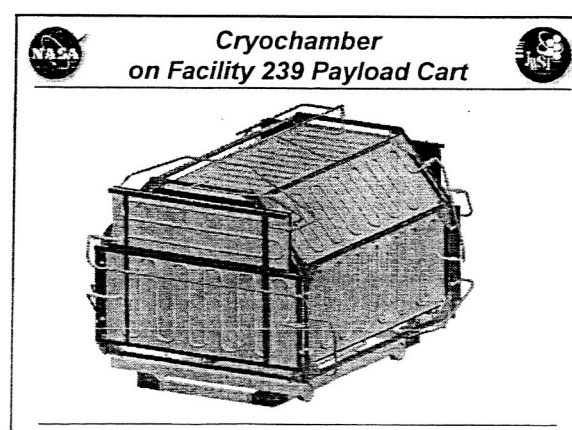
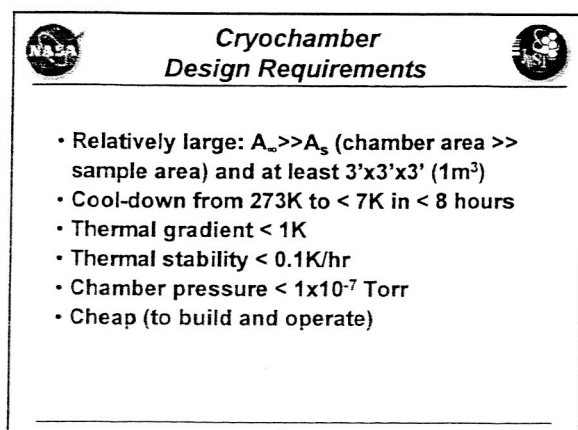
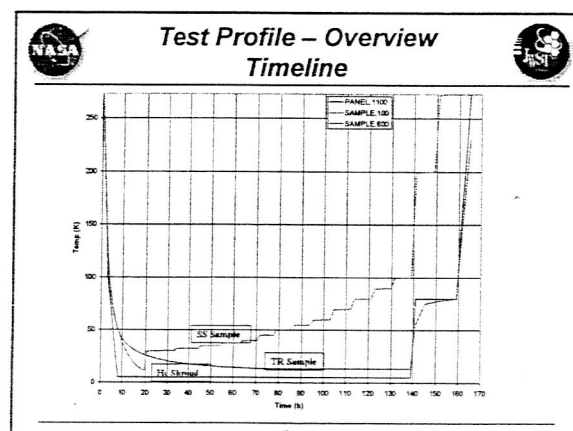
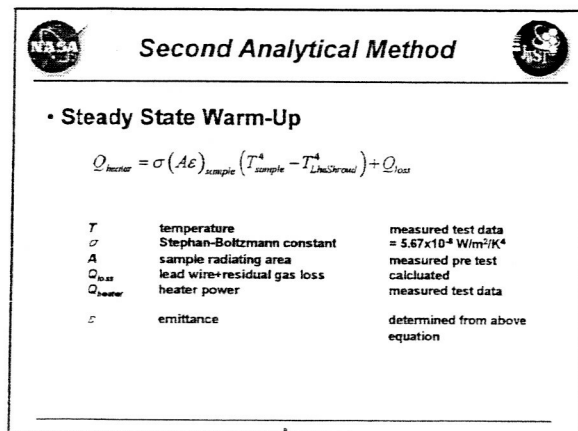
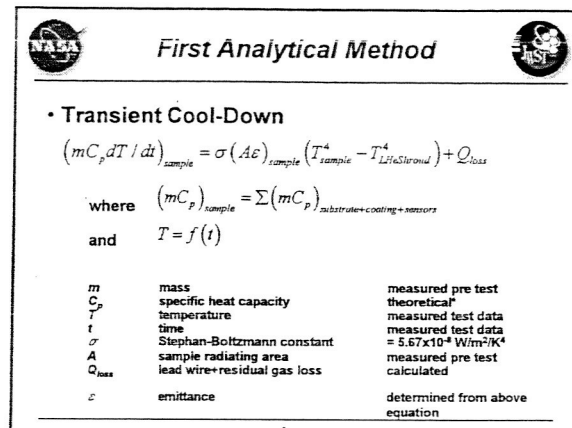
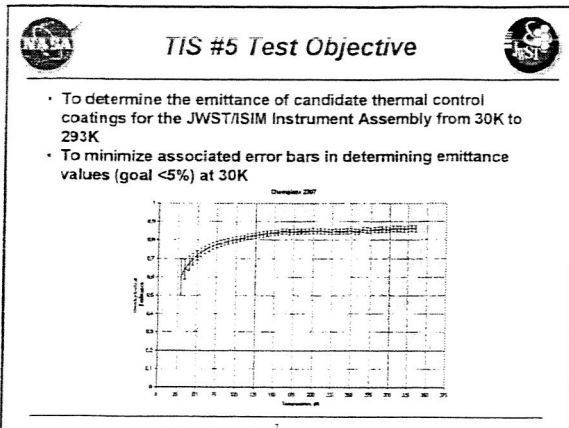
Integrated Science
Instrument Module (ISIM)

- Near Infrared Camera (NIRCam)
- Near Infrared Spectrograph (NIRSpec)
- Mid Infrared Instrument (MIRI)
- Fine Guidance Sensors (FGS)



ISIM Thermal Verification Flow



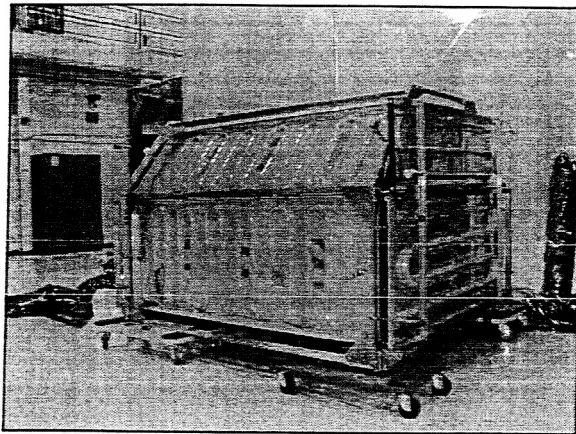
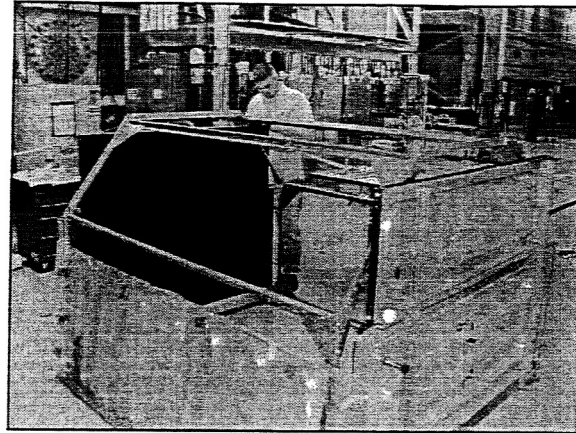




Cryochamber Design Overview



- Volume: 6'L x 4'W x 5'H (1.9m x 1.2m x 1.5m)
- Utilized 11 existing cryopanelsl
 - (5) 76" x 29"
 - (2) 76" x 23"
 - (2) 61.5" x 29"
 - (2) 54" x 23"
- Cryopanelsl painted with Aeroglaze Z307
- Supported by an "exoskeleton" frame
- Plumbed in four parallel circuits
- Covered with single-layer, two-sided VDA



Cryochamber Instrumentation



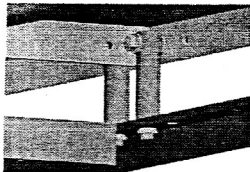
- **Temperature**
 - (20) Type T thermocouples used for fixture and tube monitoring down to LN₂ temperatures
 - (15) DT-470-CU-13 standard curve silicon diodes used for panel and tube monitoring to LHe temperatures
 - ±1K accuracy
- **Pressure**
 - NIST traceable calibrated Granville Phillips Stabil-Ion Gauge on Chamber
 - ±4% accuracy per decade from 1x10⁻² to 1x10⁻⁸ Torr



Cryochamber Thermal Isolation

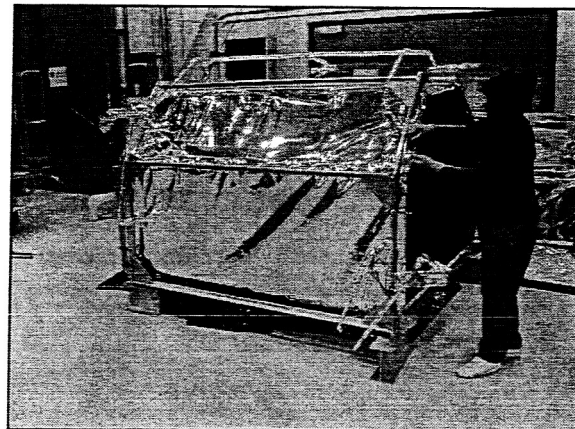



- Cryopanelsl supported by G-10 isolators with L/W=3.6




- Three mil double sided VDA over gaps between panels
- Three mil double sided VDA over all panels
- Four-layer MLI wrapped around all tubing

Calculated conduction and radiation heat loss = 10.7W






Test Sample Selection




Sample Specifications

Sample #	Substrate	Test Method	Radiating Surface	
			Front	Rear
1	A1100 Al	Steady State	Z306 Black	Z306 Black ¹
2	A1100 Al	Transient	Z306 Black	Al Tape
3	A1100 Al	Steady State	Black Kapton	Black Kapton ¹
4	A1100 Al	Transient	Black Kapton	Al Tape
5	M55J	Steady State	Bare (M55J)	Al Tape ¹
6	M55J	Transient	Bare (M55J)	Al Tape

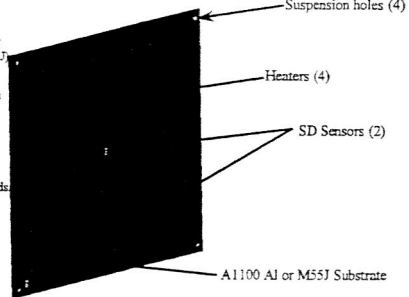
Note 1: Applied over heaters




Steady State Test Sample Configuration




- Thermal control coating applied over heaters (except M55J)
- For M55J sample heaters covered with Aluminum tape.
- Heaters for steady state samples only.
- Al tape over SD sensors & heater leads
- Sensor/heater lead wires not shown

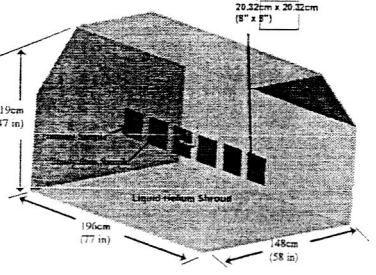





Test Sample Configuration




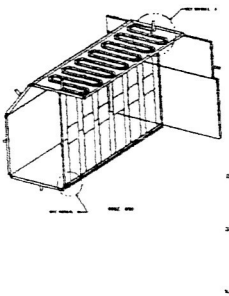
- Alternating transient / steady state samples
- Kevlar suspension not shown



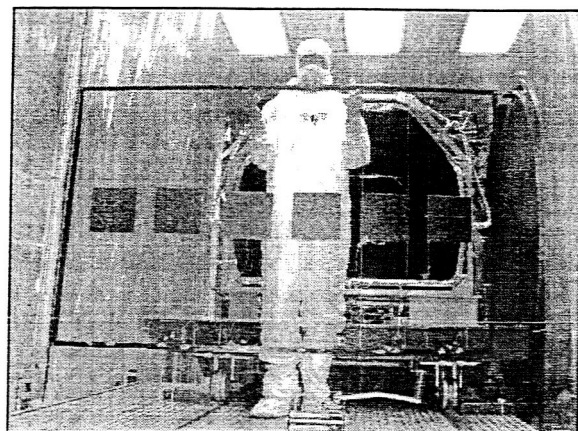



Test Sample Support Frame






- Black anodized
- Conductively coupled to He shroud
- Tension springs to attach Kevlar to frame

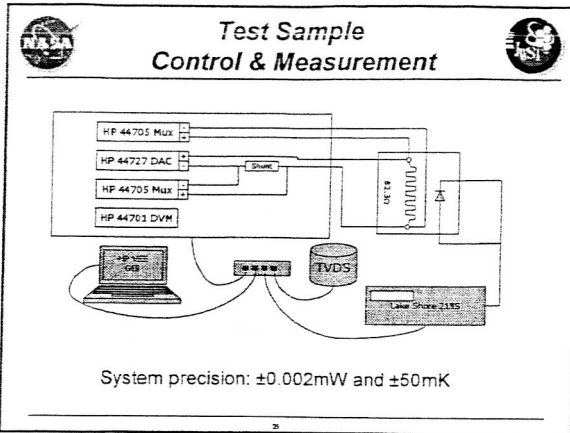




Test Sample Description



- Coatings
 - Z306 Black Paint
 - Black Kapton (2 mil; VDA backing)
 - Bare M55J-954-6 Composite
- Substrate
 - A1100 Aluminum
 - 8" x 8" x 0.020"
 - M55J / 954-6 Composite
 - 8" x 8" x 0.024" (8 ply);
- Heaters
 - Minco model # HK5174R82.3112B
 - 3" x 3" (4 per sample); wired in series
 - Kapton w. PSA backing
 - Each heater 82.3 Ohms
 - Wires
 - Heater to heater: 40AWG Cu; PTFE insulation; Aluminum tape overlay
 - Power leads: 30AWG Manganin; Formvar insulation; VDA overcoat
 - Voltage leads: 36 AWG Manganin; Formvar insulation; VDA overcoat
- Temperature Sensors
 - LakeShore model DT-47D-SD-13
 - Silicon Diode (37mg)
 - Calibrated from 4K-100K within at least +/-50mK
 - Phosphor bronze wire; 36AWG; 2 twisted pairs; Formvar™ insulation



Error Bar Determination

- All quantities in the aforementioned equations are known or measured except for the sample emissivity, ϵ_s . For either the steady-state or transient case, we can isolate this term and derive an expression in terms of the other variables.

$$\epsilon_s = f\left(A_s, A_{\infty}, A_{\text{sh}}, A_{\text{he}}, L, T_s, T_{\infty}, \epsilon_s, \epsilon_{\text{he}}, \alpha_{\text{He}}, \alpha_{\text{sh}}, P_{\text{he}}, Q_{\text{rad}}, m, C_p, \frac{dT}{dt}\right)$$

- The variance of ϵ_s is then given by

$$E_{\epsilon_s}^2 = \left(\frac{\partial \epsilon_s}{\partial A_s}\right)^2 E_{A_s}^2 + \left(\frac{\partial \epsilon_s}{\partial A_{\infty}}\right)^2 E_{A_{\infty}}^2 + \dots + \left(\frac{\partial \epsilon_s}{\partial Q_{\text{rad}}}\right)^2 E_{Q_{\text{rad}}}^2$$

Ref: "Physics Quick Reference Guide", American Inst. of Physics, p198

Emissivity Determination

- Heat Balance**
 - Transient

$$Q_c = (mC_p \frac{dT}{dt})_{\text{sample}} = Q_{\text{rad}} + Q_{\text{gas}} + Q_{\text{wire}}$$
 - Steady State

$$Q_{\text{he}} = Q_{\text{rad}} + Q_{\text{gas}} + Q_{\text{wire}}$$

where:

Q_c	sample internal energy rate of change
m	mass
C_p	Specific heat capacity
T	temperature
t	time
Q_{rad}	radiation to He shroud
Q_{gas}	residual gas conduction to He shroud
Q_{wire}	heater / sensor lead wire loss
Q_{he}	heater dissipation

Emissivity Determination

- Radiation Heat Loss**

$$Q_{\text{rad}} = \sigma A_s \epsilon_{\text{eff}} (T_s^4 - T_{\infty}^4)$$

where $\epsilon_{\text{eff}} = \left[\frac{1}{\epsilon_s} + \frac{A_s}{A_{\infty}} \left(\frac{1}{\epsilon_{\text{sh}}} - 1 \right) \right]^{-1}$

for $A_s \ll A_{\infty}$ $\epsilon_{\text{eff}} = \epsilon_s$

- σ = Stefan-Boltzmann constant
- A_s = area of the test sample
- A_{∞} = area of the shroud
- ϵ_{eff} = effective emissivity
- ϵ_s = emissivity of test sample
- ϵ_{sh} = emissivity of shroud
- T_s = sample temperature
- T_{∞} = shroud temperature

Emissivity Determination

- Residual Helium Gas Heat Loss**

$$Q_{\text{gas}} = \alpha_{\text{eff}} XYP_{\infty} A_s (T_s - T_{\infty})$$

where $\alpha_{\text{eff}} = \left[\frac{1}{\alpha_s} + \frac{A_s}{A_{\infty}} \left(\frac{1}{\alpha_{\text{sh}}} - 1 \right) \right]^{-1}$

$X = \frac{\gamma_{\text{He}} + 1}{\gamma_{\text{He}} - 1}$

$Y = \left(\frac{P_{\text{He}}}{8\pi T_{\infty}} \right)^{1/2}$

for $A_s \ll A_{\infty}$ $\alpha_{\text{eff}} = \alpha_s$

- A_s = area of the test sample
- A_{∞} = area of the shroud
- α_{eff} = effective accommodation coefficient (ac)
- α_s = ac of He @ sample temperature
- α_{sh} = ac of He @ shroud temperature
- T_s = sample temperature
- T_{∞} = shroud temperature
- P_{He} = pressure @ He shroud
- $\gamma = C_p / C_v$
- C_p = specific heat @ constant pressure
- C_v = specific heat @ constant volume
- R_{He} = Helium gas constant

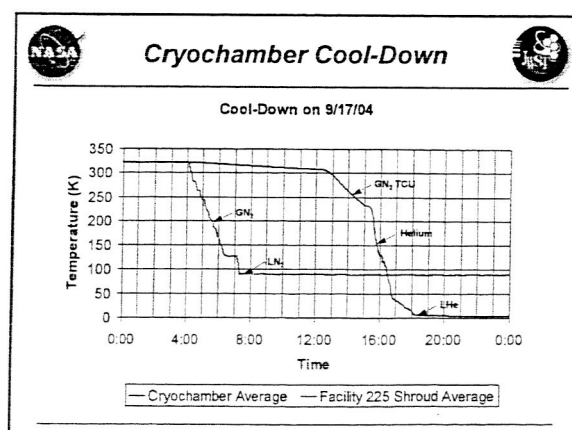
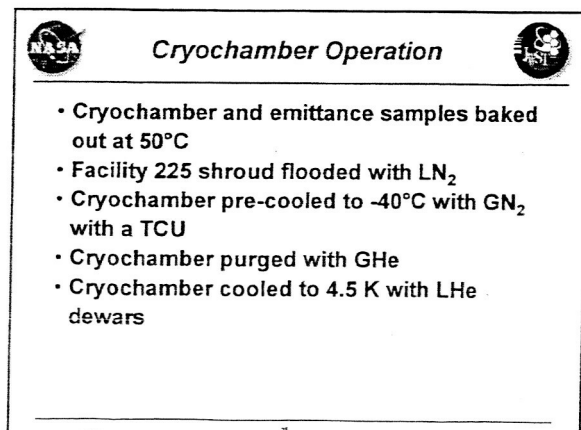
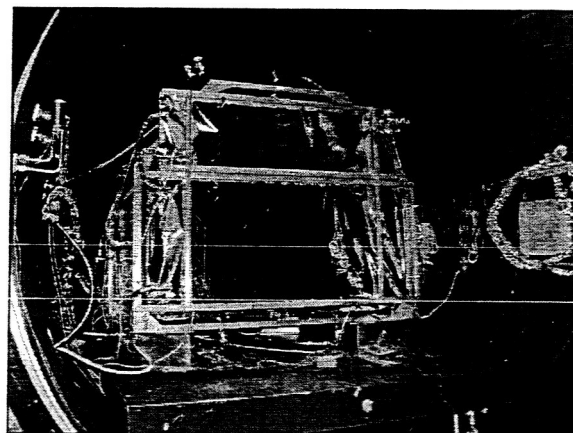
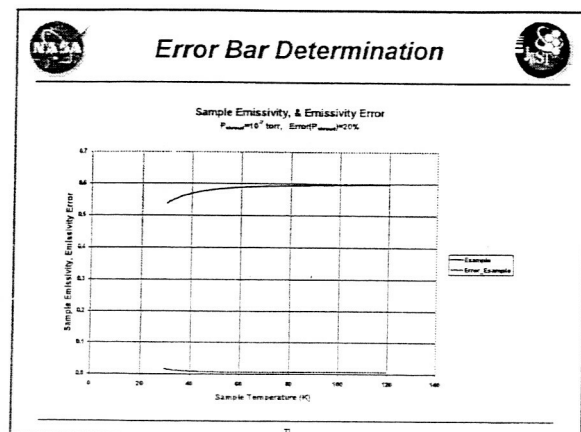
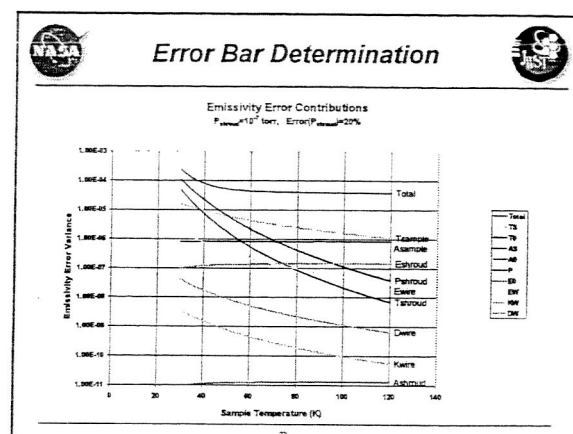
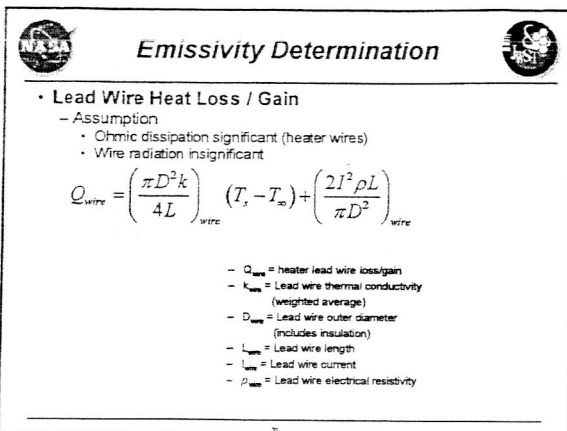
Ref: "Cryogenic Engineering", T.M. Flynn, p372 (7.9)

Emissivity Determination

- Lead Wire Heat Loss**
 - Assumptions
 - Ohmic dissipation insignificant (sensors and voltage meas)
 - Wire radiation significant
 - Long lead wires

$$Q_{\text{wire}} = \pi (0.1\sigma)^{1/2} \left(k^2 D^3 \epsilon^{1/2} \right)^{1/2} T_s^{5/2}$$

- Q_{wire} = lead wire loss
- n = Stefan-Boltzmann constant
- k_{wire} = Lead wire thermal conductivity (weighted average)
- D_{wire} = Lead wire outer diameter (includes insulation)
- ϵ_{wire} = lead wire insulation emittance
- T_s = sample temperature





Cryochamber Test Results



- All cryochamber test objectives were met
 - Cooled-down from >300K to 4.6K in less than 6 hours
 - Achieved 4.5K \pm 0.1K
 - Thermal gradient < 0.2K
 - Thermal stability < 0.05K/hr
 - Chamber pressure < 5×10^{-8} Torr
- Total cost of cryochamber was \$77,738 which included
 - Design, fabrication and construction
 - Helium transfer lines
 - Instrumentation
 - Thermal blanketing
- Helium consumption was as predicted – about 500 liters/day



Test Sample Results



- Emittance test samples
 - M55J and Z306 sample results look good
 - Z306 paint thickness an issue
 - Black Kapton delaminated from A1100 substrate
 - Steady state approach superior – less error than transient approach
- Emittance data not released
 - Parasitic losses and error bars still being characterized
 - Emittance data to be published soon



Future Considerations



- Cryochamber
 - Use larger TCU to pre-cool
 - Eliminate use of GHe as a purge
 - During cool-down
 - During dewar changes (use plug)
 - Procure second helium transfer line
 - Improve time to change-out helium dewars
- Test Samples
 - Eliminate transient samples (pending analysis results)
 - Perform test on external radiator coating candidates
 - Ball Infrared Black (BIRB), S13GLO and black anodized aluminum